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Assessing air pollution tolerance of plant species in vegetation traffic barriers in Kathmandu Valley, Nepal

Sunita Shrestha¹, Badri Baral^{2,3}, Narayan Babu Dhital^{4,5,6} and Hsi-Hsien Yang^{5*} 

Abstract

Vegetation traffic barriers along roads can be an effective structure to improve roadside air quality and to reduce human exposure to traffic air pollutants. However, the selection of the plant species should be considered as an important design parameter for vegetation traffic barriers because different plant species demonstrate different levels of tolerance to air pollutants. This study compares the air pollution tolerance of different plant species found in the vegetation traffic barriers in the Kathmandu valley. Four biochemical parameters (relative water content, leaf extract pH, total chlorophyll and ascorbic acid) and the dust-capturing potential of plants were analyzed. Out of the nine selected species, *Cinnamomum camphora* showed the highest tolerance to air pollution based on the air pollution tolerance index. Similarly, *Schefflera pueckleri*, *Psidium guajava* and *Ficus benjamina* were found to be the sensitive species, while *Ficus* sp., *Nerium oleander*, *Thuja* sp., *Dypsis lutescens* and *Albizia julibrissin* were found to have a moderate level of tolerance to air pollution. *N. oleander* had the highest dust-capturing potential. Considering both air pollution tolerance index and dust-capturing potential, *C. camphora*, *N. oleander* and *A. julibrissin* were found to be the most suitable species for the roadside plantation. The findings of this study might have important implications for plant species selection for vegetation traffic barriers.

Keywords: Air pollution tolerance index, Biochemical parameters, Dust capturing potential, Vegetation traffic barrier

Introduction

Urban air pollution is one of the major atmospheric pollution issues that is getting worse with the growing urban population, increasing traffic density and industrialization [1]. Air pollution is one of the leading risk factors for disease burden [2, 3] and causes effects ranging from mild health problems to death [2]. Around 90% of the global population lives in places where air quality does not comply with WHO air quality guidelines [4]. Transport is one of the major sectors of urban air pollution worldwide [5]. Roadside air quality is aggravated due to high traffic density, old vehicles, poor fuel quality, poor road and inadequate inspection and maintenance programs [6]. The

environmental performance index ranked Nepal's air quality at the 178th position out of 180 in 2020 [7]. Kathmandu, the capital city of Nepal with dense settlement areas and below global average open green space per capita [8], has been reported to be one of the highly polluted cities in Asia.

It is difficult to completely control the emission of air pollutants at the source. Thus, reducing human exposure is one of the important aspects of air quality management. Vegetation might help reduce human exposure to traffic emissions through dry deposition of pollutants on vegetation surfaces [9]. Vegetation traffic barrier is one of the several promising passive control systems for air pollution [10]. It offers a porous medium that provides a barrier between vehicular emissions and adjacent population by influencing local turbulence and modifying natural dispersion [9]. It is a cost-effective and

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environmentally friendly option against other technological and mechanized methods to mitigate air pollution. It provides several other ecosystem co-benefits like temperature and storm water regulation, noise reduction, etc. It has been found that plants can filter certain pollutants through absorption, adsorption and metabolism [11]. Thus, plants act as an important sink of air pollutants [12]. Deposition rates of air pollutants on vegetation have been found higher than those on the built-up structures [13]. Vegetation provides sites for gravity or wind-blown settlement of air pollutants [14]. Furrowed areas of leaf surfaces can provide effective sites for particulate matter deposition [15]. Moreover, urban vegetation may also help reduce the urban heat island effect [16]. So, vegetation traffic barriers with a proper design could provide the benefit of reducing air pollution exposure. Planting vegetation for air-quality improvement has been well accepted in many developed countries [11]. However, not all plant species offer equal benefits in minimizing urban air pollution. Some plant species may even act as the source of pollutants such as biogenic volatile organic carbon. Studies have shown that the selection of plant species for roadside plantation might have a substantial effect on volatile organic carbon emissions [17]. Therefore, plant species selection should be considered carefully while designing urban green belts and vegetation traffic barriers [18].

Plant's ability to tolerate air pollutants depends on its biochemical, physiological and morphological characteristics [11]. Air pollution tolerance index (APTI) describes the inherent quality of plants to tolerate air pollution. It is one of the important parameters that could be considered for the selection of traffic barrier plant species. It is an important tool to categorize plants based on their tolerances or sensitivity levels to air pollutants. APTI of plants has been described with four biochemical parameters: total chlorophyll, relative water content (RWC), ascorbic acid and leaf extract pH. Pollution-induced alterations in a single parameter may not depict a clear picture of the situation. So, four biochemical parameters are considered to obtain an empirical value representing the APTI of plants [19]. The gradual disappearance of chlorophyll and yellowing of leaves is one of the common effects of air pollution that reduces photosynthesis. Ascorbic acid is an important electron donor in photosynthesis [20]. Photosynthetic activity is strongly dependent on pH [21]. These biochemical parameters are dependent on each other and most responsive to air pollution. Based on APTI values, low APTI plant species can be used in low pollution areas as bio-indicators, while high APTI plant species can be used in highly polluted areas to mitigate air pollution [22, 23].

There are several studies conducted on the suitability of plant species to be used in urban green belts [22–24]. Most of these studies have been conducted in India and China. However, the findings of these studies cannot be simply generalized over different regions because of the differences in biogeographic and climatic conditions in different areas. Thus, the present study was conducted in the Kathmandu valley to evaluate air pollution tolerance and dust-capturing potential of plant species used in the vegetation traffic barrier along the Kathmandu-Bhaktapur road section.

Materials and methods

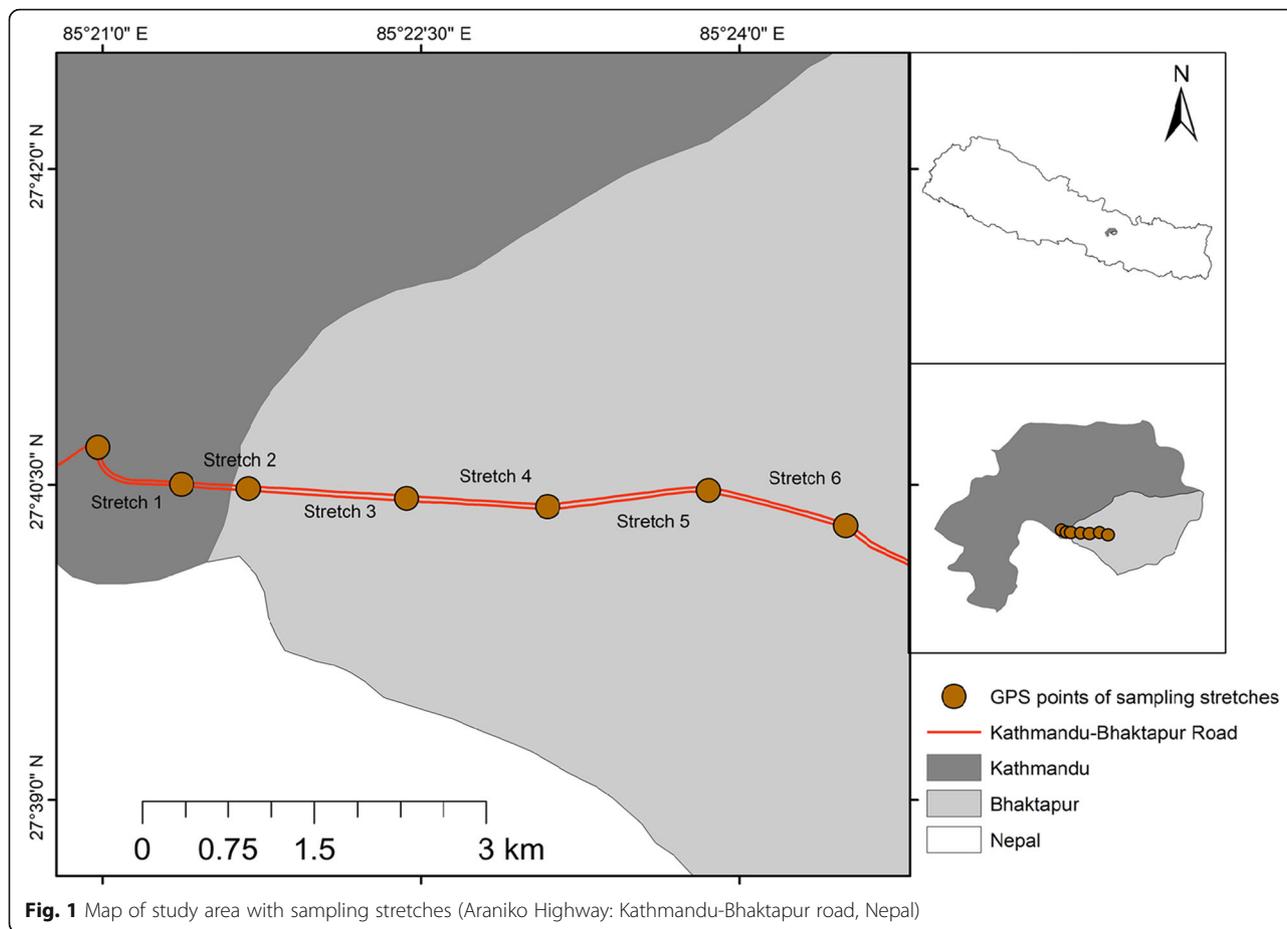
Study area

Samples for the present study were collected from the Kathmandu-Bhaktapur road section from Koteshwor bus stand (27°40'39.93" N and 85°20'58.46" E) to Sallaghari (27°40'18.26" N and 85°24'29.99" E) at an elevation of 1312–1310 m asl (Fig. 1). The road section is a six-lane highway that connects Kathmandu district with Bhaktapur district in the Kathmandu valley [25]. The study area features a warm and temperate climate with an average annual temperature of 19.5 °C and about 1089 mm annual precipitation in 2017 [26]. The main sources of air pollutants in the study area are road traffic and industries.

Sampling and analysis

The study was undertaken during the month of January–March, 2018. Six stretches, each of 1 km length, were selected along the Koteshwor-Sallaghari road section for sample collection. The sampled road section featured approximately 3 m wide vegetation traffic barriers in the middle of the road to separate opposing traffic lanes. Different plant species have been grown in the traffic barrier. The traffic barrier vegetation had nearly a uniform height. Nine most abundant plant species found along the traffic barrier were selected for the analysis. The selected plant species were *Albizia julibrissin*, *Cinnamomum camphora*, *Dyopsis lutescens*, *Ficus benjamina*, *Ficus* sp., *Nerium oleander*, *Psidium guajava*, *Schefflera pueckleri* and *Thuja* sp.

For each of the selected plant species, fresh mature leaves were collected from 2 m height during the morning hours (08:00–11:30). Sampling was done in triplicate. The sample leaves were kept in polythene bags and brought to the laboratory in an icebox (Marina cooler, 18S) for further analysis. The samples of each plant species obtained from the same road stretch were mixed to make a composite sample for each road stretch. Thus, there were six composite samples, each corresponding to one of the six road sections for each species. Three replicate analyses were done for each composite samples. Moreover, to estimate the dust-capturing potential of



the leaves, three matured leaves of the selected plant species were washed in the early morning (08:00–11:00) from each of the six road stretches. The upper and lower surfaces of leaves were cleaned using a fine brush and distilled water. The selected leaves were marked and left for 24 h. The marked leaves were cut from the petiole on the next day. The leaves were put in pre-weighted zip lock bags and brought to the laboratory. After the leaves were air-dried, a five-digit electronic balance (Kern, ABT-BA-def-0911) was used for the measurement of leaf weights. After that, dust on leaves was cleaned with the help of fine brush and distilled water and blotted dry with blotting paper. The leaves were again air-dried and weighted. The leaf area was measured using ImageJ software [27].

RWC

Three different weights of the leaves (fresh weight taken immediately after collecting leaves, turgid weight after immersing in water overnight and the dry weight after drying in hot air oven at 70 °C overnight; Vitco, Universal hot air oven) were used for calculating the RWC of leaves [28]. The RWC was calculated using Eq. (1).

$$RWC = \frac{FW - DW}{TW - DW} \times 100\% \tag{1}$$

where, FW = fresh weight, DW = dry weight, and TW = turgid weight.

Total chlorophyll

A crushed leaf sample (5 g) was taken, and 10 mL of 80% acetone was added to it. Then, the sample was left aside for 15 min for thorough extraction. The leaf extract so obtained was decanted into centrifuge tubes and was centrifuged (Remi, R-8C) at 2500 rpm for 10 min. Then, the absorbance was taken at 645 nm and 663 nm using a spectrophotometer (SSI, UV 2101) after calibrating it against reagent blank. The total chlorophyll content was calculated using Eq. (2) [29, 30]. The details of the methods can be found elsewhere [29].

$$TCh = [20.2(A645) + 8.02(A663)] \times \left[\frac{v}{(1000 \times W)} \right] \tag{2}$$

where, TCh = total chlorophyll (mg g⁻¹), A645 = absorbance at 645 nm, A663 = absorbance at 663 nm, V = total

volume of the extract (mL), and W = weight of the sample (g).

Leaf-extract pH

A part of the leaf sample (5 g) was crushed and homogenized in 50 mL deionized distilled water. The sample was filtered and the pH of leaf suspension was measured using a pH meter (YSI, 1200).

Ascorbic acid

A part of fresh leaf tissue (1 g) was crushed and put in a test-tube. Then, 4 mL oxalic-ethylenediaminetetraacetic acid extracting solution was added to the test-tube followed by 1 mL orthophosphoric acid, 1 mL of sulphuric acid (5%), 2 mL ammonium molybdate (5%) and 3 mL distilled water. The solution was allowed to stand for 15 min and the absorbance was measured at 760 nm with a spectrophotometer (SSI, UV 2101). The concentration of ascorbic acid was obtained from the standard curve of ascorbic acid in mg mL^{-1} and converted to ascorbic acid content per gram dry weight [31]. Further details of the analytical methods can be found elsewhere [31].

APTI

APTI was calculated using Eq. (3) [19, 23].

$$\text{APTI} = \frac{[A(T + P) + (R)]}{10} \quad (3)$$

where,

A = Ascorbic acid content (mg g^{-1}) (dry weight), T = Total chlorophyll content (mg g^{-1}), P = leaf extract pH, and R = RWC (%).

APTI values were categorized into three groups (Table 1) as suggested by Bharti et al. [22] and Ogunkunle et al. [32].

Dust-capturing potential

The dust-capturing potential of leaves was calculated using Eq. (4):

$$W = \frac{(W_1 - W_2 - W_3)}{A} \quad (4)$$

where W = dust-capturing potential (g cm^{-2}), W_1 = weight of leaf with dust and zip lock bag (g), W_2 = weight of leaf after removing dust (g), W_3 = weight of zip lock bag (g), and A = total area of leaf (cm^2).

Results and discussion

RWC

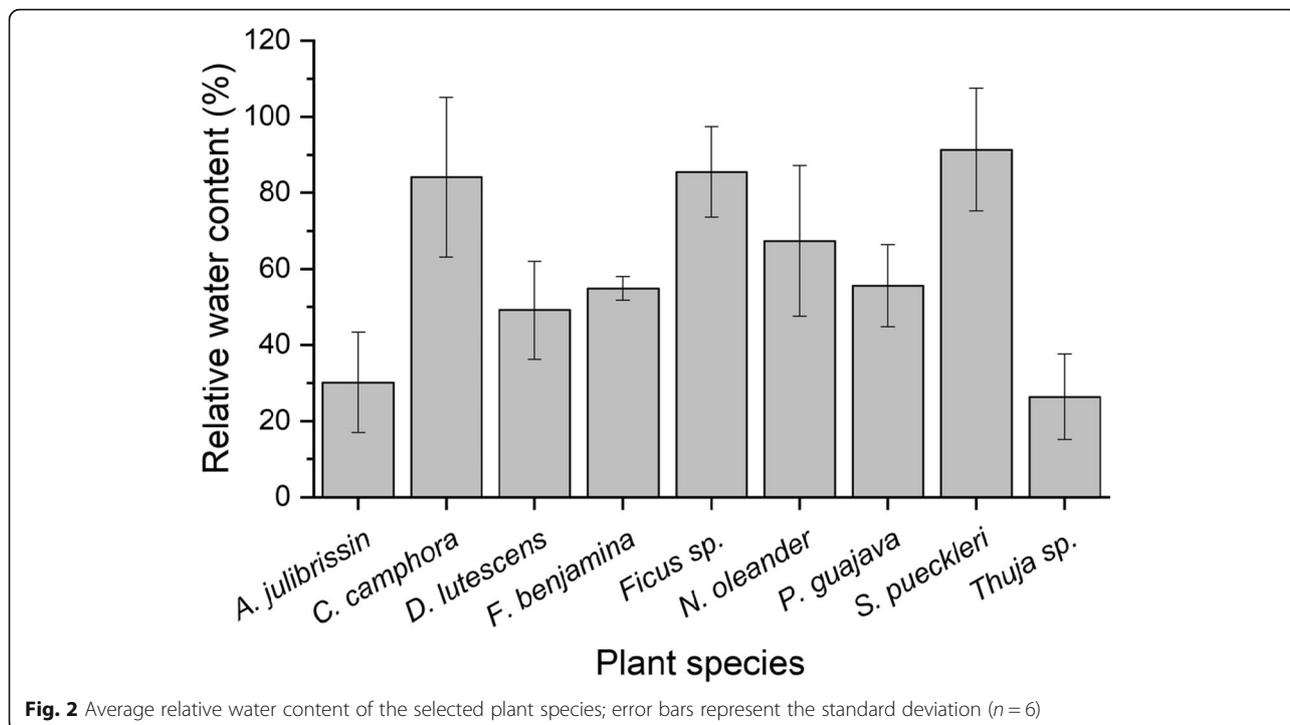
RWC of the selected plant species ranged from 26.4 to 91.4% (Fig. 2). RWC of most of the plant species was found > 40% in the present study. RWC can be as high as 98% in fully turgid transpiring leaves, while it can be as low as 30–40% in severely drying leaves depending on the plant species [33]. Higher RWC has been reported in plants from polluted sites [24, 34]. The maximum RWC was found for *S. pueckleri* (91.4%) followed by *Ficus* sp. (85.5%), *C. camphora* (84.2%), *N. oleander* (67.4%), *P. guajava* (55.6%), *F. benjamina* (54.9%), *D. lutescens* (49.2%), *A. julibrissin* (30.2%), and *Thuja* sp. (26.4%) (Fig. 2). High RWC helps plant species to survive in long dry seasons [35]. In contrast to the results of the present study, Kanwar et al. [24] report high RWC in *Thuja* sp. (92.3%). The observed differences could be because of the differences in the sampling period, site, irradiance, temperature, humidity and soil salinity [36]. A decrease in RWC lowers stomatal conductance and hence CO_2 assimilation [37]. Net CO_2 exchange, CO_2 assimilation and photosynthetic potential become zero at very small RWC (approx 40%) [37]. Under stressed conditions, such as exposure to air pollution, transpiration rates of plants could increase. A higher RWC gives plants a better tolerance capacity against air pollution [38].

Total chlorophyll

The total chlorophyll content was found to range from 0.106 to 1.38 mg g^{-1} (Fig. 3). The maximum total chlorophyll content was found in *C. camphora* (1.38 mg g^{-1}) followed by *A. julibrissin* (1.26 mg g^{-1}), *D. lutescens* (0.417 mg g^{-1}), *S. pueckleri* (0.364 mg g^{-1}), *P. guajava* (0.238 mg g^{-1}), *F. benjamina* (0.199 mg g^{-1}), *Thuja* sp. (0.192 mg g^{-1}), *Ficus* sp. (0.140 mg g^{-1}) and *N. oleander* (0.106 mg g^{-1}). In a study conducted by Li et al. [39], the total chlorophyll content in 823 plant species ranges from 1.2 to 22.6 mg g^{-1} . The total chlorophyll contents in the selected plant species were relatively lower in the present study. This could be an effect of the stress induced by air pollutants. Total chlorophyll is considered as an index of photosynthetic activity, growth and biomass productivity [40, 41]. Degradation of photosynthetic pigments has been widely used as an indicator of air pollution, and a decrease in chlorophyll content shows that plants are more sensitive to air pollution [42]. Therefore, *Thuja* sp., *N. oleander*, *Ficus* sp., *F. benjamina* were likely to be more sensitive to air pollution than *C. camphora* and *A. julibrissin*. A decrease in chlorophyll content decreases the productivity of plants

Table 1 Categories of plant species based on air pollution tolerance index

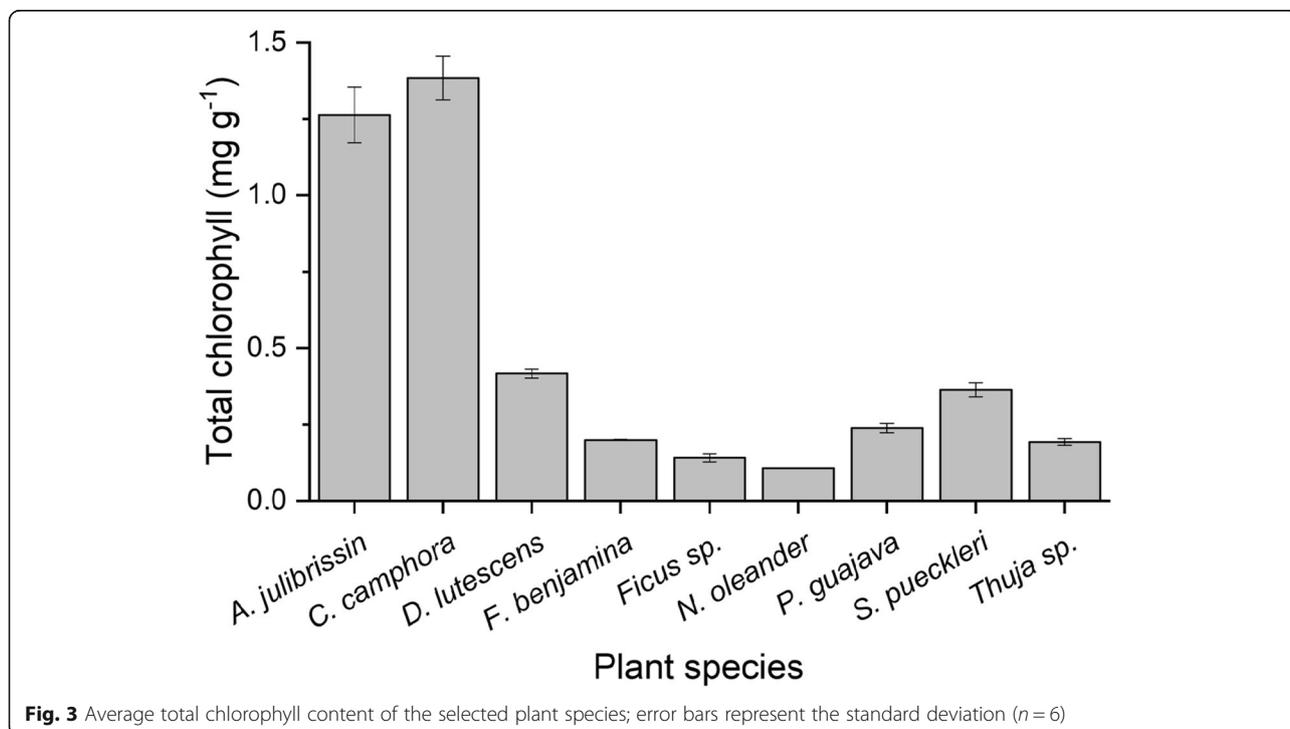
S/N	APTI value	Response
1	1–11	Sensitive
2	12–16	Intermediate
3	≥ 17	Tolerant



and hence the resistance of plants to air pollution. Air pollutants like sulphur dioxide, nitrogen dioxide, carbon dioxide and suspended particulate matter may lower the chlorophyll concentration [40] as the pollutants enter into tissues through stomata and cause partial denaturation of chloroplasts.

Leaf extract pH

The leaf extract pH of the selected plant species ranged from 5.13 to 8.44 (Fig. 4). The highest pH was observed for *F. benjamina* (8.44) followed by *C. camphora* (7.71), *Thuja sp.* (7.69), *S. pueckleri* (7.66), *P. guajava* (7.58), *Ficus sp.* (7.29), *N. oleander* (5.94), *D. lutescens* (5.48),



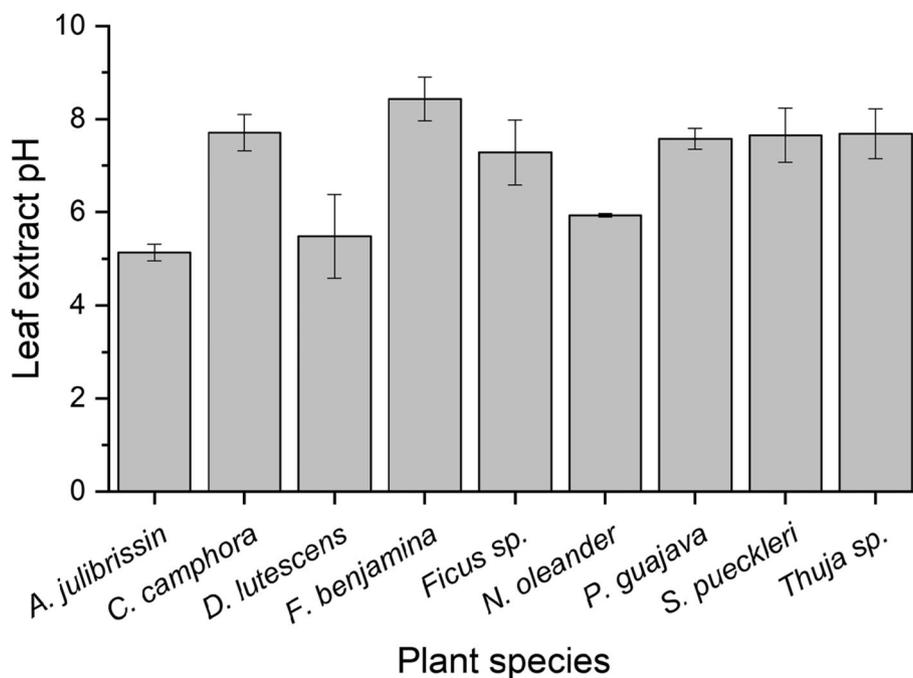


Fig. 4 Average leaf extract pH of the selected plant species; error bars represent the standard deviation (n = 6)

and *A. julibrissin* (5.13). Plants having leaf extract pH around 7 and higher are more tolerant of air pollution than those having low pHs [38]. Most of the plant species selected in the present study had pH values above 7. A lower leaf extract pH can be observed in the plants

exposed to acidic pollutants such as SO_x , NO_x , CO_2 [43]. The activity of ascorbic acid is also pH-dependent which is high at higher pH and low at lower pH. Therefore, high leaf extract pH makes plants more tolerant of air pollution [38]. Lower leaf extract pH may reduce the

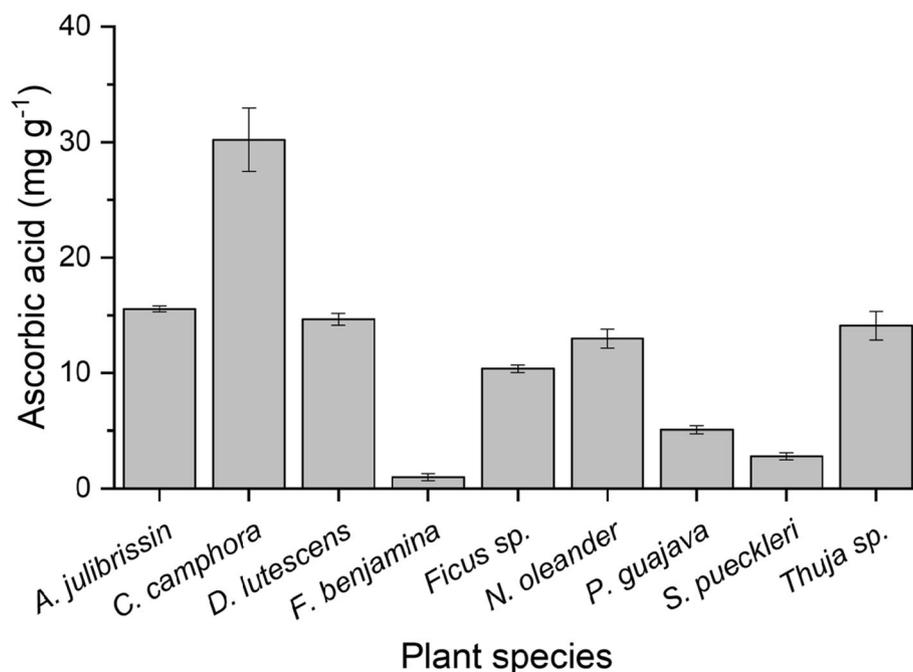


Fig. 5 Average ascorbic acid of the selected plant species; error bars represent the standard deviation (n = 6)

chlorophyll content of the plant species and hence the capacity to tolerate air pollution.

Ascorbic acid

The ascorbic acid content in the selected plant species ranged from 0.975 to 30.2 mg g⁻¹. The highest ascorbic acid content was observed for *C. camphora* (30.2 mg g⁻¹) followed by *A. julibrissin* (15.6 mg g⁻¹), *D. lutescens* (14.7 mg g⁻¹), *Thuja* sp. (14.1 mg g⁻¹), *N. oleander* (13.0 mg g⁻¹), *Ficus* sp. (10.4 mg g⁻¹), *P. guajava* (5.08 mg g⁻¹), *S. pueckleri* (2.79 mg g⁻¹) and *F. benjamina* (0.975 mg g⁻¹) (Fig. 5). Ascorbic acid is an antioxidant that provides resistance to plants in a stressed condition. With the increase in pollution, ascorbic acid content also increases to combat the stressed condition [22]. It acts as a powerful reductant [44], electron donor, scavenges free oxygen radicals, facilitates the reduction of sulphite to hydrogen sulphide and reduces the toxicity of SO₂ [45]. Plants having high ascorbic acid possess resistance to SO₂ [45]. So, *C. camphora*, *A. julibrissin*, *N. oleander* might have a better capacity to combat air pollution. Ascorbic acid helps in the defense mechanism and tolerating the ill effects of air pollutants [46].

APTI

APTI of the selected plant species ranged from 6.33 to 36.0. The highest APTI was exhibited by *C. camphora* and the lowest by *F. benjamina*. The order of APTI values of the selected plant species was: *C. camphora* > *Ficus* sp. > *N. oleander* > *Thuja* sp. > *D. lutescens* > *A. julibrissin* > *S. pueckleri* > *P. guajava* > *F. benjamina*. *C. camphora* was found to be a tolerant species; *S. pueckleri*, *P. guajava*, *F. benjamina* were found to be the sensitive species and *Ficus* sp., *N. oleander*, *Thuja* sp., *D. lutescens*, *A. julibrissin* were found to have intermediate tolerance to air pollution (Table 2). Unlike the finding of the present study, *F. benjamina* has been reported as a tolerant species in a study conducted by Pandey et al. [47]. This could be because of the fact that APTI of

Table 2 Average (n = 6) air pollution tolerance index of the studied plant species

S/N	Name of plant species	APTI (Mean ± SD)	Response
1	<i>Cinnamomum camphora</i>	36.0 ± 5.6	Tolerant
2	<i>Ficus</i> sp.	16.3 ± 2.3	Intermediate
3	<i>Nerium oleander</i>	14.6 ± 3.1	Intermediate
4	<i>Thuja</i> sp.	13.7 ± 1.5	Intermediate
5	<i>Dyopsis lutescens</i>	13.6 ± 1.0	Intermediate
6	<i>Albizia julibrissin</i>	13.0 ± 1.6	Intermediate
7	<i>Schefflera pueckleri</i>	11.4 ± 2.1	Sensitive
8	<i>Psidium guajava</i>	9.5 ± 1.4	Sensitive
9	<i>Ficus benjamina</i>	6.3 ± 0.7	Sensitive

plants may vary from place to place due to geographic and climatic variations [30]. It also varies because of differences in air quality, temperature, humidity, etc. [48]. The sensitive plant species identified in the present study could be potentially used as bio-indicators of air quality while the tolerant species could be used in vegetation traffic barriers and urban green belts [22, 23, 34].

Dust-capturing potential

The median dust-capturing potentials of the selected plants ranged from 0.00026 to 0.0018 g cm⁻² (Table 3). The maximum dust-capturing potential was found for *N. oleander* followed by *A. julibrissin*, *S. pueckleri*, *C. camphora*, *G. jasminoides*, *Ficus* sp. and *F. benjamina*. The plant species with the higher dust-capturing potentials help in reducing particulate matter in the roadside atmosphere [49]. They play as a biological air filter. Shrubs with foliar leaves arrest more particulate matter than large trees [50]. Plants have different inherent morphological traits like phyllotaxy, leaf shape, size and texture, presence or absence of hairs, stomatal frequency, surface roughness, stomatal density, and trichome length that determines their dust collecting capacity [51].

The results of the present study suggest that *C. camphora*, *N. oleander* and *A. julibrissin* were tolerant of air pollution considering both APTI and dust-capturing potential. The air pollution tolerance of plant species varies with seasons [52] and with several environmental variables [48]. A limitation of the present study is that it covers a small spatial and temporal scale. However, it provides some important insights and foundation for further research in the geographical area considered in the present study. Future works might be done covering a larger temporal and spatial scale and considering meteorological and air quality parameters.

Conclusions

This study evaluated the suitability of plant species for vegetation traffic barriers. Among the nine selected plant species, *Cinnamomum camphora*, *Nerium oleander* and

Table 3 Median (n = 6) dust capturing potential of the studied plant species

S/N	Plant species	Dust capturing potential (g cm ⁻²)	
		Median	IQR ^a
1	<i>Cinnamomum camphora</i>	0.00064	0.0030
2	<i>Ficus benjamina</i>	0.00026	0.00028
3	<i>Ficus</i> sp.	0.00030	0.00014
4	<i>Nerium oleander</i>	0.0018	0.0013
5	<i>Schefflera pueckleri</i>	0.00069	0.00051
6	<i>Albizia julibrissin</i>	0.00088	0.00042
7	<i>Gardenia jasminoides</i>	0.00031	0.00013

^aInterquartile range

Albizia julibrissin were found to be the most suitable species to be used in the vegetation traffic barriers based on air pollution tolerance and dust-capturing potential. The finding of the present study might be useful for designing urban green belts and vegetation traffic barriers in the Kathmandu valley.

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Authors' contributions

SS conceptualized the study, conducted laboratory and field works. SS, BB, NBD and HHY contributed to the data analysis and manuscript writing. All authors read and approved the final manuscript.

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Availability of data and materials

All data generated or analyzed during this study are included in the article.

Competing interests

The authors declare they have no competing interests.

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